Case Study 3: Adapting Modern Crop Improvement Tools for Africa

Component: Breeding, variety release, and maintenance

Subtitle: Experiences in the introduction, testing, release, commercialization, seed production, and marketing of improved varieties using molecular, genetic engineering and gene editing tools.

Executive Summary:
Over the past 30 years, advances in the development and application of molecular tools in crop improvement have expanded rapidly as well as adapted to the African context in the case of molecular markers, double haploid technology, and genetic engineering. Biosafety frameworks with supporting laws, personnel, and facilities have been an important process in the adaption and adoption of these tools across Africa to ensure their safe use and that their products are safe for our food system and environment.

Context:
Three different steams of modern biotechnology tools to support crop improvement have emerged and are used in Africa: molecular markers, double haploid technology, and genetic engineering. Within each of these, there is a diverse set of methods and applications that have different merits as well as potential risks that are mitigated through proper testing and certification under national laws regulating their use. The most widely accepted is the use of molecular markers to track specific gene sequences that are associated with specific traits of interest such as tolerance to abiotic or biotic stresses, nutritional enhancement, or allocation of lines into different heterotic groups in the case of hybrid breeding program. A more recent advance has been the development of double haploid technology that enables homozygous lines to be generated in a couple of breeding cycles in under one year that would have normally taken 6 or more years depending on the crop (Chaikam et al. 2018). The most controversial technology has been genetic engineering to introduce gene sequences into a crop through a process called transformation. The oldest approach is called ballistics in which a small pellet coated with desired DNA sequences is shot into a tissue culture callus of a crop line that is randomly inserted into the crop genome that is then confirmed using biochemical and molecular markers. This was largely replaced by agrobacterium transformation that uses flanking DNA segments to place the desired DNA into a specific location in the genome. The latest approach is called gene editing and uses CRISPR-Cas9 which is an immune defense system optimized to introduce RNA-guided changes to the crop genome and then rely on the crop's own DNA repair systems to repair the DNA sequence so it can be stably inherited (Zhang et al., 2018).

Molecular markers have evolved over time to offer a wide range of marker platforms summarized by Yali (2022). Molecular markers have supported crop improvement and the seed sector that include:- variety identification and purity testing, population and diversity studies, construction of genetic maps, identifying quantitative trait loci (QTLs), major gene mapping, mutation mapping, pyramiding traits, marker assisted backcrossing. Beyond crop improvement, molecular markers have helped in the tacking of diverse crop pathogens such as yellow rust of wheat (Walter et al., 2016) and biotypes of nematodes on potato (Hoolahan et al., 2016) that are indistinguishable under a microscope.

Genetically engineered (GE) or genetically modified (GM) crops have been very controversial and yet in a recent study documented the benefits to farmers in South Africa through higher yields due to stem borer control in white maize that translated to $5 million in ecosystem benefits over 17 years (Ala-Kokko, et al. 2021). GE varieties have been approved for commercial release in Nigeria, Malawi, Kenya, Sudan, Burkina Faso, Egypt, and South Africa, while contained and confined testing of them has been performed in Tanzania, Mozambique, Zimbabwe, Uganda, and other countries. Despite the documented benefits to farmers in developing countries, including those in Africa, many policymakers and farmers in Africa remain hesitant about the use of GM crops, and they need more information about their potential, benefits, costs, and safety in the African context. GM crops may, for example, enhance productivity, improve pest and weed control, and increase tolerance to drought and salinity. These crops may also improve public health through reductions in pesticide applications and enhanced nutrition, such as vitamin A–enhanced rice.

Crops and traits need for GM crops in Africa - Beginning in 1998, South Africa is the major grower of GM crops. GM crops under either research or commercialized for use in Africa include cotton, maize, cassava, cowpea, sorghum, potato, banana, sweet potato, sugar cane, coconut, squash, and grape. These are being promoted for different traits. As well as disease, insect and virus resistance some of the research projects focus on traits particularly crucial for Africa like drought resistance and biofortification.

Challenges and Objectives:
Why Africa needs GM crops - Africa needs to flog-leap food production to achieve food security due to recurring challenges of the increased human population, climate change-induced biotic and abiotic stresses (drought, weeds, insect pests, and diseases), low productivity of crops, and low-quality agricultural products.

Prerequisites for a country to test, release and commercialize GM crops: GM crops have a role in food production though they are not a "magic bullet" for food security. For a country to test, release and commercialize GM crops, they need to have a regulatory network of laws and regulations to govern the process as well as biosafety facilities and skilled manpower for development and regulations. The R&D institutions also require policies and protocols in place. Finally, there is a need for education to raise awareness among farmers and other public and private sector stakeholders involved in the seed value chain including marketing and stewardship of the products.

Different GM crops in Africa: Due to its diversity of agroecologies, history, and culture, requires and adopted diverse staple food and cash crops. GM varieties of various crops including cotton, maize, cassava, cowpea, sorghum, potato, banana, sweet potato, sugar cane, coconut, squash, and grape have been tested and some commercialized in Africa. It is only in South Africa (maize, cotton, and soybean), and the Sudan (Cotton) where GM crops have commercialized, and fully functional seed systems are available. The rest are at various stages of testing.

Interventions:
Experiences of GM crops at different stages of development, testing, release, seed production, and commercialization in Africa.

Following the commercial release of GM crops in the developed countries (USA, Canada, Brazil, Argentina, and China) and the reports on the benefits of such crops in boosting productivity, reducing losses due to biotic and abiotic stress as well as the potential contribution to food quality, African countries were interested in growing GM crops to boost food security. Despite the critical debates that ensued, African countries signed the Cartagena protocol and established national legal frameworks that included biosafety laws with competent authorities and trained manpower to varying levels before 2000.

The GM event may be either directly commercially released for farmers to cultivate or introgressed into locally adapted and farmer-preferred non-GM cultivars that are already released and grown by the farmers (Akinbo et al., 2021). The introduction of new biotechnology products to farmers is a process that includes comprehensive testing in the laboratory, greenhouse, and field over some time. The process provides answers to questions about the safety of the products before being introduced into the environment and marketplace. This is the first step in regulatory approvals. The output of the research and development phase of the product development cycle is the identification of a safe and performing event for advancement to regulatory testing, likely commercialization, and general release.

The commercial release of the GM crop for cultivation requires the approval of biosafety regulatory packages through the evaluation and approval of the GM event by competent national authorities (Akimbo et al., 2021). This evaluation comprises a review of environmental, food, and feed safety data as provided for in the relevant national legal instruments.

The process of the commercial release of new crop varieties in countries with established formal seed systems is guided by well-defined procedures and approval systems and regulated by the Seed Acts and implemented regulations. In countries with seed laws, no crop varieties are approved for commercial cultivation before the fulfillment of the national performance trials (NPT) and the distinctness, uniformity, and stability (DUS) tests, as well as before the approval by the National Variety Release Committee (NVRC).

All GM crop projects were started with the hope that regulatory processes will be run efficiently for timely approval for commercialization in the respective countries (Table 1). The assumption was that biosafety aspects would be demonstrated rapidly in introduced products as well as for products developed within the country. These would then be tested for commercial release through NPTs, and seed production be equally seamlessly conducted as for conventional varieties. It is for this reason that most GM projects in Africa were started in the 2000s.

Results:

- By 2021, a significant number of GM crops have been introduced for testing and eventual deregulation and commercialization in 13 sub-Saharan countries (Table 1). Though these were started in the late 1990s, with exception of South Africa where the first GM crops were released in 1998, the few commercial releases were only done in the 2000s. This is largely because African countries face key challenges in the deployment of GM crops due to incongruities in the processes for effective and efficient commercial release while simultaneously ensuring food and environmental safety. Countries are attempting to subject GM crop varieties to different testing, release, seed production, and growing processes from those of conventional varieties.
- There is a need for countries to increase the capacity of biosafety authority staff for efficient and effective assessment of biosafety aspects of GM crops as well as the capacity of seed release authorities to separate biosafety from variety release systems.

- Policymakers need to be provided with science-based information so that countries can reach sovereign decisions, in terms of biosafety, while ensuring environmental and human safety.
- The interface between biotechnology regulations is that safety data presented to the regulatory institutions should be trusted for event approval, and the superior performance of the crop for varietal registration should be within the role of the mandated institution and enhances the responsibility of the separation rules.
- Seed production for GM crops should then only be different from conventional crops during EGS only to prevent low-level presence and adventitious presence in seed quality control.

Supporting Visuals or Quotes:

“Africa should not ignore new technologies that can facilitate good seed production, processing, and marketing” – Justin Rakotoarisao, Secretary General, AFSTA.

“Once a GM event crop is approved for biosafety, its process for release and seed production should be similar to those of conventional variety.” - Justin Rakotoarisao, Secretary General, AFSTA.

Future Plans:

Africa stands to benefit from crops developed using modern biotechnology tools to increase crop productivity, reduce losses due to pests and diseases and abiotic stresses (e.g., drought, low soil fertility) and increase the nutritional quality of staple crops. To date, 13 African countries developed biosafety frameworks and started R&D for a significant number of diverse GM crop species. However, these crops have remained at the R&D stage without reaching commercialization, in part due to more rigorous variety release processes to ensure food and environmental safety.

Call to Action (CTA)/Key takeaways:

The African seed systems for varieties developed using biotechnology tools is still at an early stage and concerted efforts by the African Union and its member states are needed to enable Africa to reach its objective of food security.

References

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Table 1: Status of Agricultural Biotechnology crops in Africa

Notes: CC – Crop Composition [nutritional value], CFT – Confined Field Trial, DR – Drought Tolerant, IR – Insect Resistance, HT- Herbicide Tolerant, NUE – Nitrogen Use Efficient. *Source: Akinbo et al. 2021*

	Country	Crop	Trait	Year started	Status in July 2022	Yr. approved for commerce	Seed Status 2022
1	Burkina Faso	Cowpea	Insect Resistance (IR)		CFT		
2	Burkina Faso	cotton	IR		Commercialized	2008	
2	Cameroon	Cotton	IR, Herbicide Tolerance (HT)		CFT		
3	Ethiopia	Maize	IR, Drought Tolerance (DT)	2018	CFT		
4	Ethiopia	Cotton	IR	2015	Commercialized	2018	
5	Eswatini	cotton	IR		Commercialized		
6	Ghana	Rice	NUE, DT, Salinity Tolerance (ST)		CFT		
7	Ghana	Cowpea	IR		CFT		
8	Ghana	Maize	IR, DT		CFT		
9	Kenya	Sorghum	Crop Composition (CC)		CFT		
10	Kenya	Potato	Disease Resistance (DR)		CFT		
11	Kenya	Cotton	IR		Commercialized	2019	
12	Kenya	Sweet Potato	Virus Resistance (VR)	1999	CFT		
13	Kenya	Maize	IR, DT	2008	Recommended for Release		
14	Kenya	Maize	DT		CFT		
15	Kenya	Cassava	DR		NPT		
16	Kenya	Banana	DR		CFT		
17	Malawi	Cowpea	IR		CFT		

18	Malawi	Cotton	IR		Commercialized		
19	Malawi	Banana	VR		CFT		
20	Mozambique	Maize	IR, DT		MLT		
21	Nigeria	Cotton	IR		Commercialized		
22	Nigeria	Cowpea	IR		Commercialized		
23	Nigeria	Sorghum	CC		CFT		
24	Nigeria	Cassava	CC		CFT		
25	Nigeria	Cassava	CC, DT		CFT		
26	Nigeria	Rice	NUE, DR		CFT		
26	Nigeria	Maize	IR, DT, HT		CFT		
27	South Africa	Sugarcane	CC		CFT		
28	South Africa	Sugarcane	IR, DT, HT, NUE		CFT		
29	South Africa	Soya bean	IR		Commercialized		
30	South Africa	Cassava	CC		CFT		
31	South Africa	Maize	IR, DT, HT		Commercialized	1998	
32	Sudan	Cotton	IR		Commercialized	2012	
33	Tanzania	Maize	IR, DT, HT		CFT		
34	Uganda	Rice	NUE, DT, ST		CFT		
35	Uganda	Potato	DR		CFT		
36	Uganda	Maize	IR, DT, HT, NUE		CFT		
37	Uganda	Cassava	DR		CFT		
38	Uganda	Banana	IR		CFT		
39	Uganda	Banana	DR		CFT		
40	Uganda	Banana	CC		CFT		